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Request for grant of a patent

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1.	Your reference	DC299.P01.027
2.	Patent application number *(The Patent Office will fill in this part)*	**0200563.5**
3.	Full name, address and postcode of the or of each applicant *(underline all surnames)*	Roger Aylward 8301996001 Martin Pemberton t/a Transport Design International 12 Waterloo Park Estate Bidford on Avon Warwickshire B50 4JH
	Patents ADP number *(if you know it)*	8302006001
	If the applicant is a corporate body, give the country/state of its incorporation	
4.	Title of the invention	Route Navigation, Guidance & Control - Automated Vehicle Steering & Safety Braking
5.	Name of your agent *(if you have one)* "Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	Chris J Tillbrook 1 Mill Street Warwick CV34 4HB
	Patents ADP number *(if you know it)*	3963808002
6.	If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number	Country / Priority application number *(if you know it)* / Date of filing *(day / month / year)*
7.	If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application	Number of earlier application / Date of filing *(day / month / year)*
8.	Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:* *a) any applicant named in part 3 is not an inventor, or* *b) there is an inventor who is not named as an applicant, or* *c) any named applicant is a corporate body.* *See note (d))*	No

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Continuation sheets of this form	-
Description	11
Claim(s)	1
Abstract	1
Drawing(s)	3 +3

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10. If you are also filing any of the following, state how many against each item.

Priority documents	-
Translations of priority documents	-
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	-
Request for preliminary examination and search *(Patents Form 9/77)*	-
Request for substantive examination *(Patents Form 10/77)*	-
Any other documents *(please specify)*	-

11. I/We request the grant of a patent on the basis of this application.

Signature Chris J Tillbrook & Co. Date 10 Jan '02

Chris J Tillbrook & Co 10 January 2002

12. Name and daytime telephone number of person to contact in the United Kingdom

Michelle Hardy
01926 490929

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Notes

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DUPLICATE

Route Navigation, Guidance & Control
- Automated Vehicle Steering & Safety Braking

This invention relates to navigation, guidance and control - and is particularly, but not exclusively, concerned with automated (road) vehicle steering.

Some aspects of the invention are also concerned with emergency (road) vehicle braking.

A particular challenge is to preserve directional control under emergency braking, by addressing both braking and steering.

Terminology

The term 'navigation' is used herein to embrace determination of position, orientation or direction.

In practice, navigation can be indirectly by reference to an abstract inferential or representational map, chart or frame of reference, positive identification of physical ground features, or radio fixes.

The term 'guidance' is used herein to embrace (re-) directional prompting of (re-) orientation.

The term 'steering' is used herein to embrace physical pointing or assertion of direction.

As such, steering mechanisms include ground-engaging wheel, skid or track runner articulation and/or selective or differential braking.

Automated Steering

Automated vehicle guidance and steering systems are known *per se.*

Similarly, automated emergency or progressive, cadence braking systems are known for rail vehicles - albeit where steering is not a consideration.

Backup

However, their application to passenger carrying public (transport) service vehicles (PSV's) requires meeting stringent safety standards, typically including a fail-safe, or backup, steering facility.

Such a back-up typically requires a judicious combination of steering and braking, to slow and halt a vehicle, while maintaining a prescribed route.

A backup steering system should thus be able to keep the vehicle on course, for a set time or distance, at any point on the route, whether on a straight or sharp curve or bend, and regardless of instantaneous vehicle speed - or indeed route gradient or slope (downward or upward).

Urban Environment

Emergency considerations aside, for public transport vehicles to operate in a tightly confined, urban environment - typically congested with vehicular and pedestrian traffic - it is desirable that a vehicle strictly follows a designated route, identifiable by other traffic, whether or not a vehicle occupies the route.

Pedestrianised Route

It is also common to allow public transport vehicular traffic over so called pedestrianised, and thus otherwise largely traffic-free (aside from occasional emergency vehicles and deliveries at prescribed off-peak times) zones.

Similar considerations apply to more restricted private sites, such as roadways in theme parks, zoos, country house estates, etc.

Constrained Route

This could also allow a vehicle to negotiate a much more tightly defined and laterally constrained route (in relation to vehicle size) than if, say, a driver had total freedom of movement.

Predetermined Pathway or Route

To that end, it is known to provide a predetermined pathway over a prescribed route - relieving a vehicle driver or operator of the burden of steering, in favour of attention to (obstacle and pedestrian) hazard avoidance, essentially by braking.

Traditionally, a tramway or road form of railway, requires a dedicated route pathway, shared with, but enjoying priority over other vehicles.

Limited Manoeuverability

A tram may have limited manoeuverability or freedom of manoeuvre, constrained to its prescribed pathway.

A visible or marked pathway - say, a painted surface line, or a differentially coloured surface, enables pedestrians or other vehicular traffic to be aware of potential conflicting tramway traffic.

A tram is generally accorded precedence over other vehicles, given its limited freedom of manoeuvre, if operating as intended by following a prescribed path.

Thus departure from an 'expected' path could create an even greater conflict hazard, requiring prompt recognition and remedial corrective (re)action.

A tramway need not rely upon bespoke track configured as guidance rails.

Rails entail a prohibitive capital installation expense not always justified and which would restrict tram adoption.

Thus, for a light urban tram, a route pathway may be contrived by other than a physical contact rail.

Remote Sensing

A diversity of pathways and attendant sensors may be contrived.

Thus a pathway may be a line marking upon the ground surface, with an optical on-board sensor.

Alternatively, the pathway may be a buried (electrical current-carrying) cable, used in conjunction with on-board electromagnetic field sensors.

Wayside route beacons can also play a part, as confirmatory position reference stations.

Such guidance systems are common in industrial environments for direction of robotic vehicles.

Moreover, aspects of positional control are known for certain industrial machine tools, to determine relative cutting tool and work piece paths.

However, these are generally concerned with localised areas, that is generally within the immediate machine environment or confines, rather than protracted external, remote pathways.

Emergency Backup

With public transport vehicles, strict Health and Safety, Construction and Use, regulations apply.

Fail-Safe

Thus a secondary system may be required as a fail-safe back-up to a primary steering system, such as a pathway sensor.

Should the vehicle sensor lose 'track' of the pathway, rather than simply activate an emergency stop procedure - which could prove hazardous to vehicle occupants - some emergency backup steering system would be advantageous.

Statement of Invention

According to one aspect of the invention,
a (dual redundant) vehicle steering system,
comprises a primary system,
referring to a physical reference line;
and a secondary system,
referring to an independent reference store,
expressed as a sequential instruction table,
configured as an emergency backup,
implemented upon failure of the primary system.

More particularly, a prescribed route is subdivided into sequential segments, each accorded a respective steering instruction, in relation to a preceding segment.

Route segments can be expressed as a plurality of way points, way point bearings, and [arcuate] paths,

Arc Curvature

Arcuate paths are defined about arc centres, laterally offset from the route, as turning points.

A turn might be expressed as an arc of prescribed radius about a reference centre point.

Arcs may be regarded as convex (ie curved towards) or concave (ie curved away from) a centre point.

Similarly, directions along arcs can be defined as anti-clockwise or clockwise.

For the purposes of distinction, arcs can be assigned positive or negative designator signs.

Rather than purely circular arcs, and better to reflect route subtleties of form, more complex curves may be adopted.

Examples would include, (fragmentary) conic sections, such as ovals, hyperbola or parabola, or trigonometric functions, such as sine waves, requiring more elaborate geometric definition.

Mathematical curve generation - such as so-called Bezier functions - by interpolation between way points may be used.

Stepping Stones

Successive route segments can be referenced relatively or mutually, say as 'stepping stones' from one segment to another.

Reference Beacons

However, in order to avoid large accumulated errors, supplementary 'downstream' confirmatory reference points, such as radio beacons, or wayside triggers, may be taken into account.

Preview Mode

Smooth and progressive steering requires some knowledge-based anticipation or preview of the route ahead, enabling a pro-active, rather than merely belated reactive, steering (input) action.

This is particularly so for strict adherence to a well defined route, with minimal departure tolerance.

A driver can look ahead and subconsciously mentally prepare, but if distracted, driver actions can become overly retrospective, post-corrective and disjointed.

Certain aspects of the invention relate variously to automated steering, backup steering and preview steering action or operational modes.

Embodiments

There now follows a description of some particular embodiments of a vehicle emergency steering and braking system according to the invention, by way of example only, with reference to the accompanying diagrammatic and schematic drawings, in which:

Figure 1 shows a block schematic layout of principal elements of a primary steering system with parallel secondary or emergency backup steering and braking systems;

Figures 2A through 2C show operation of the secondary or emergency steering (and braking) system of Figure 1, under automatic guidance system failure, and 'normal' driving under automated guidance control.

Thus, more specifically:

Figure 2A shows a vehicle under automatic guidance system control, travelling along a guideway during 'normal' driving;

Figure 2B shows the same vehicle, upon failure of the automatic guidance system, being brought safely to a halt by a secondary guidance system according to the invention; and

Figure 2C shows how the emergency steering system can be used to assist the automatic guidance system to enhance 'normal' driving performance;

Figures 3A through 3C show route analysis by segmentation for the secondary steering system of Figures 1 and 2B/2C;

More specifically:

Figure 3A shows a route segmentation in straight and curved segments;

Figure 3B shows a mathematical abstraction of the route of Figure 3A, with nominal plus or minus signs accorded respectively to clockwise or anti-clockwise arc transit direction or orientation; and

Figure 3 shows a tabulated analysis of route segments, expressed as a sequentially stacked look-up table of definitive segment factors, such as arc radius, length and attendant vehicle steering angle.

Referring to the drawings, a (road) vehicle 40, such as a bus or tram, has dual (redundant) steering systems, respectively designated primary 10 and secondary 20, directing a common steering actuator 11, in turn coupled to vehicle steered wheels 19.

Alternatively, the primary and secondary steering systems 10, 20 are allocated separate respective actuators (not shown).

Primary Steering System

A primary steering system 10 tracks a route reference designator line 30, with a physical presence - such as a buried electrical cable, or optical surface marking - along a route 31.

A detector module 16 detects departure of the vehicle 40 from that reference line 30.

In this example, a detector module 16 is coupled to a transmitter head 24, generating an output beam 23, and a receiver head 25 for a return beam 28.

This would represent a typical optical beam sensor arrangement for a passive route surface line marking.

However, transmitter and receiver heads may be combined.

Moreover, in the case of a buried, current-carrying reference cable, which radiates electromagnetic waves, a receiver head only is required.

Any such departure - beyond prescribed tolerances - is recognised by the detector, fed to a primary steering command module 14, for interpretation and issue of an appropriate corrective (return-to-track) signal direction for the steering actuator 11.

In issuing such directions, the command module 14 may take account of factors such as vehicle speed and roadway surface condition, to avoid over-abrupt control correction.

Secondary Steering System

The secondary steering system 20 comprises an intercoupled steering facility 20A, emergency braking facility 20B and en-route radio beacon reference facility 20C.

In this example, the secondary steering system 20 is configured as an emergency back-up to the primary system 10 and so operates on a different principle.

That is, reliance is not placed upon the physical route track reference line 30, but rather an 'abstraction' of it, indicated by chained line 50 in Figures 2B and 2C.

This notional line 50 is an independent route referral source, expressed in terms of a sequential incremental instruction catalogue - such as tabulated in Figure 3B.

More specifically, as depicted in Figure 3A, a required route 31 is sub-divided, by careful analysis, into a sequence of compact 'manageable' segments 36, for progress monitoring and (instruction) control.

Each segment 36 is defined by a length and a curvature.

Curvature dictates a steering angle setting for the steering actuator 11.

Curvature is expressed as a radius 39 of a (nominally) circular arc about an arc centre 38.

Arithmetic qualifier plus (or positive) and minus (or negative) signs are assigned according to arc orientation or direction with respect to an arc centre point - vis clockwise or anti-clockwise, to ensure appropriate steering direction.

Arc centre position 38 can be defined in relation to an associated segment 36 start or end point 37.

Some segments 36 are straight (ie no curvature) and some curved.

The length or vehicle duration (time scale) of each segment 36 reflects operational considerations.

Thus, for example, such diverse factors as route complexity (vis how straight, or convoluted), anticipated transit speed, en route hazards, and braking performance, admit consideration.

The resolution or detail of segments 36 matches, or is compatible with, the precision of the (direct sensory reference) primary steering system 10.

Precision can be supplemented, or cross-checked, with ancillary en route references, such as wayside (radio) beacons 21, of the en-route facility 20C, in order to avoid progressive error accumulation.

Thus a positive (low power) radio beacon local passage or transit, or triangulation fix of multiple (higher power) beacons can re-set the current segment 36 and the position thereupon.

A route (look-up) store or memory 18 is pre-loaded with a so-called 'look-up' table, of such sequential incremental route progress segments 36, such as set out in Figure 3C.

Progress is monitored independently with reference to the route store data 18.

This secondary system 20 monitoring is thus a backup to the primary system 10 and its own attendant monitoring and control.

Emergency Braking

The secondary steering system is coupled to an emergency braking facility 20B, comprising an emergency braking command module 29 and a brake actuator 26, coupled to a brake mechanism 17 in each vehicle wheel 19.

A coordinator module 22 links the emergency steering facility 20A with the emergency braking facility 20B.

Primary Steering System Failure

Generally, no initiative is taken by the secondary system 20, to direct vehicle steering -

or counteract or over-ride the primary system 10, unless and until a (major) failure of the primary system 10 arises and is recognised.

Such recognition may be triggered by the primary detector 16 or the primary steering command module 14 or the secondary steering command module 15 recognising a departure from instructions prescribing the route abstraction 50.

Otherwise, there would be a risk of the primary and secondary steering systems 10, 20 operating continually in conflict or 'competition', with possible contradictory corrective directions and response mis-interpretation.

A major failure might be the primary system 10 losing track altogether of the physical reference line.

This might be expressed as a detector 16 signal loss, say through a departure from the reference line 30 beyond the detector range (say, a loss of detector return signal 28), or some errant detector 16 output signal or system failure.

Upon recognising a primary system 10 failure, the emergency steering system 20 steps in to:

- preserve directional control through steering action; and
- apply (progressive) vehicle braking.

For ongoing steering direction, the secondary system 20 relies upon its route reference source 18.

That is, by access to the look-up table in the route store 18, the secondary system 20 'knows' the past, immediate present and future route segments 36.

The secondary steering command module 15, duly primed by the route store 18, can direct the vehicle steering actuator 11 accordingly.

In order to obviate conflict, or 'competitive direction' of the steering actuator 11 by the primary steering system, the primary system 10 can be disabled, or at least uncoupled from the steering actuator 11.

This can be achieved with an arbitrator module 12, to which both the steering command outputs of the primary steering module 14 and secondary steering module 15, are applied.

The arbitrator 12 thus determines whether the primary or secondary steering systems 10, 20 directs the common steering actuator 11.

Interpolation

Rather than simply elect one and reject the other, the arbitrator 12 could 'blend' or 'merge' (eg interpolate) steering outputs from the primary and secondary steering command modules 14, 15 respectively.

This is elaborated upon later, under the heading 'Route Preview Mode'.

Generally, the route store 18 could be loaded with multiple alternative routes and adapted for different vehicle steering and braking performance.

Routes and vehicle modes could be software selectable, with provision for route update.

Route (up and down) gradients, camber (side slope) and surface condition (wet, icy or dry) 'weighting' could also be addressed as steering and braking stability considerations.

Route Preview Mode

The sensor 25 of the primary steering system 10 detector module 16 is essentially local to the vehicle and 'downward' looking at the immediately underlying, or marginally ahead, route line 30.

Thus the primary steering system 10 is essentially 'reactive', in response to a local route segment 36, and so could benefit from some 'anticipatory' or preview facility.

The advance route knowledge available from the route store 18 could contribute to just such a preview.

It is envisaged that supplementary steering direction input from a route preview could enhance steering performance in 'normal' driving mode, otherwise supervised by the primary steering system 10.

In practice, preview direction could be achieved by feeding stored preview route knowledge interpreted by the secondary steering system 20, to the steering actuator 11.

This might be termed steering 'cross-coupling' by joint commands to the arbitrator module 12.

Indeed, preview control direction - implemented as an instruction 'overlay' - could reduce, but not necessarily pre-empt, raw 're-active' direction from the primary steering system 10.

Generally, the vehicle would be less likely to make radical excursions from the route line 30, with the benefit of a preview of its future path.

Preview insight could be used in conjunction with a speed limiter module (not shown).

Thus, a modest increase in vehicle speed could be admitted when route conditions allow, such as over a straight route segment

Conversely, when the vehicle approaches a known route hazard, such as a bend or junction, a decrease in speed can be effected by disabling of an accelerator and/or pre-application of the brake actuator, for negotiating the hazard.

Journey comfort for passengers could be enhanced through smoother and more progressive vehicle direction and handling.

Moreover, journey times could be reduced by judicious use of vehicle speed, without abrupt transitions.

The flexibility of the system is such as to accommodate ancillary sub-routes, or departures from the primary route, in emergency situations.

Thus, say, each route segment or segment cluster, representing the normal route could be allied with a 'run-off' sub-route, to allow a vehicle to be brought to a kerb side - rather then left stranded in the middle of a highway or thoroughfare.

This option assumes such departure would be safe - not least in relation to the expectations of other road users.

Route and braking can be changed to reflect vehicle loading and route conditions (even visibility), such as a fully laden vehicle in slippery conditions.

Multiple Vehicles

Although the system has been described in relation to an individual vehicle, it is applicable in principle to multiple individual vehicles upon a common track 30.

Communication between vehicles 40, progressing in tandem upon a common route 30, could be through, say, a buried electrical route cable or radio.

The supplementary radio beacon reference facility 20C could be used to communicate between vehicles 40.

Individual and relative vehicle speeds could be adjusted accordingly, in order to preserve even vehicle spacing and avoid bunching - thus spreading the route traffic capacity more evenly.

Collision risks could also be reduced for vehicles 40 in close queued proximity.

Component List

10	primary steering system
11	steering actuator
12	arbitrator
14	primary steering command module
15	secondary steering command module
16	detector module
17	brake actuator
18	route (look-up) store
19	vehicle wheel
20	secondary steering system
20A	steering facility
20B	emergency braking facility
20C	radio beacon reference facility
21	radio beacons
22	co-ordinator module
23	output beam
24	transmitter head
25	receiver head/sensor
26	brake actuator
28	return beam
29	emergency braking command module
30	route line
31	pathway/route
36	route segment
37	route way point
38	arc centre
39	arc radius
40	vehicle
50	notional route

Claims -

1.

A (dual redundant) vehicle steering system, comprising a primary system (10), referring to a physical reference line (30); and a secondary system (20), referring to an independent reference store (18), expressed as a sequential instruction table, configured as an emergency backup, implemented upon failure of the primary system.

2.

A steering system, as claimed in Claim 1, wherein a prescribed route (50) is subdivided, into sequential segments (36), each accorded a respective steering instruction, in relation to a preceding segment.

3.

A steering system, substantially as hereinbefore described, with reference to, and as shown in, the accompanying drawings.

4.

A vehicle incorporating a steering system, as claimed in any of the preceding claims.

5.

An emergency combined steering and braking system, for a (road) vehicle, using accumulated sequential pre-stored route data, to determine current position and future steering action, in order to follow a prescribed route, and to trigger braking action, consistent with vehicle route speed and onward route profile, and thereby to bring the vehicle safely to a halt, while preserving directional control, and adherence to the prescribed route.

Abstract

A (dual redundant) vehicle steering system, employs a primary system (10), referring to a physical reference line (30); and a secondary system (20), referring to an independent reference store (18), expressed as a sequential instruction table, configured as an emergency backup, implemented upon failure of the primary system; the system allows co-ordinated vehicle steering and braking, for adherence to a prescribe route.

{Figure 1}

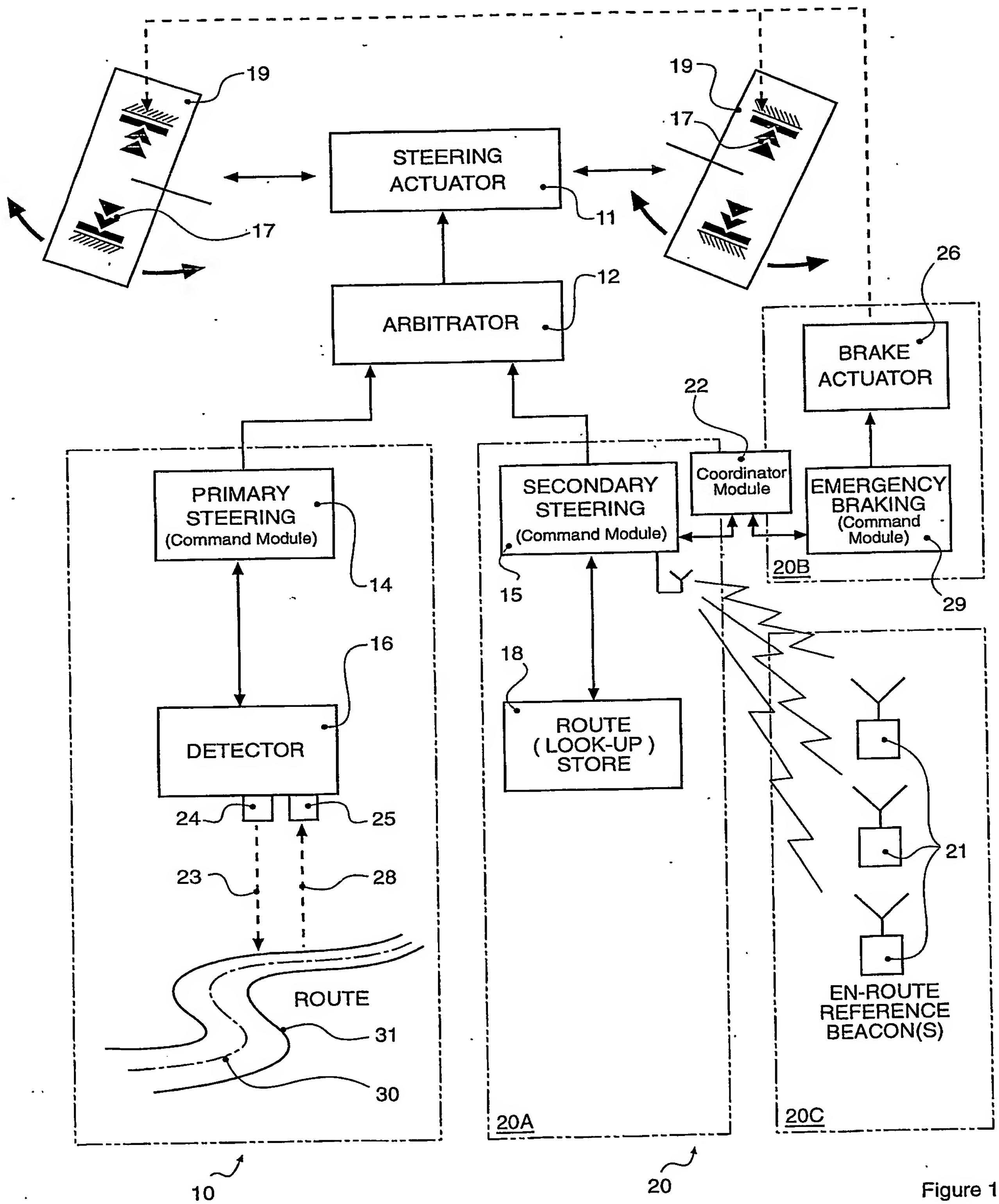
STEERING ACTUATOR
11
19
17
19
17
ARBITRATOR
12
26
BRAKE ACTUATOR
22
Coordinator Module
PRIMARY STEERING (Command Module)
14
SECONDARY STEERING (Command Module)
15
EMERGENCY BRAKING (Command Module)
29
20B
16
DETECTOR
18
ROUTE (LOOK-UP) STORE
24
25
23
28
21
ROUTE
31
30
EN-ROUTE REFERENCE BEACON(S)
20A
20C
10
20

Figure 1

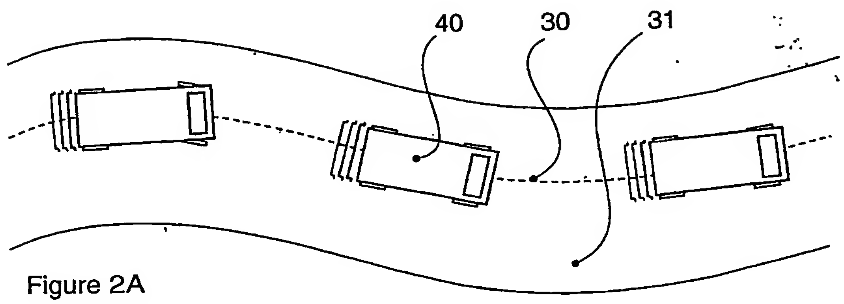

Figure 2A

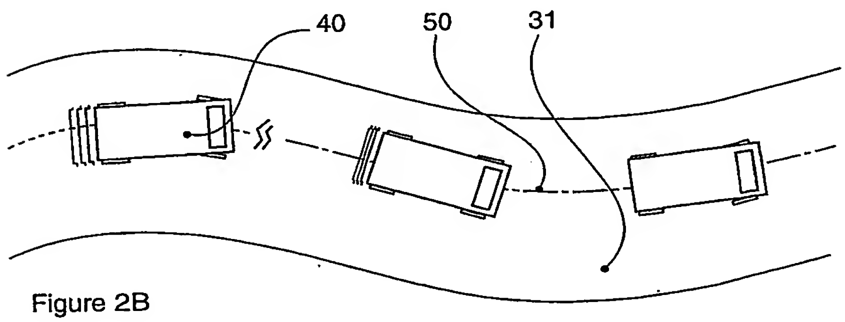

Figure 2B

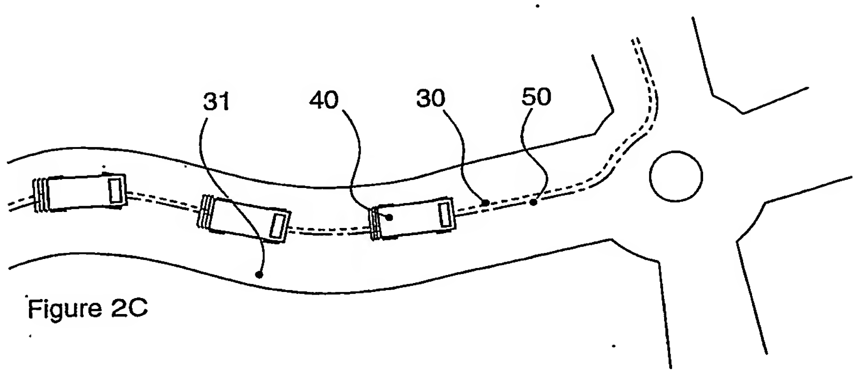

Figure 2C

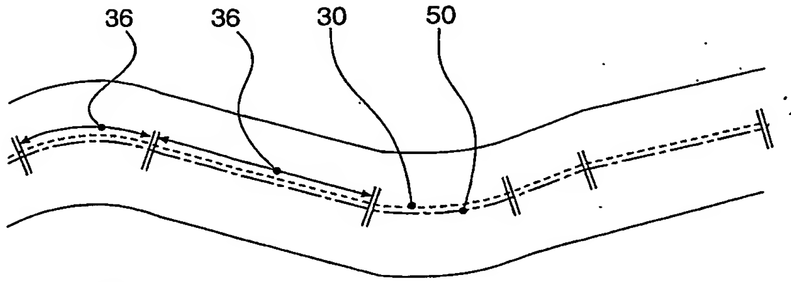

Figure 3A

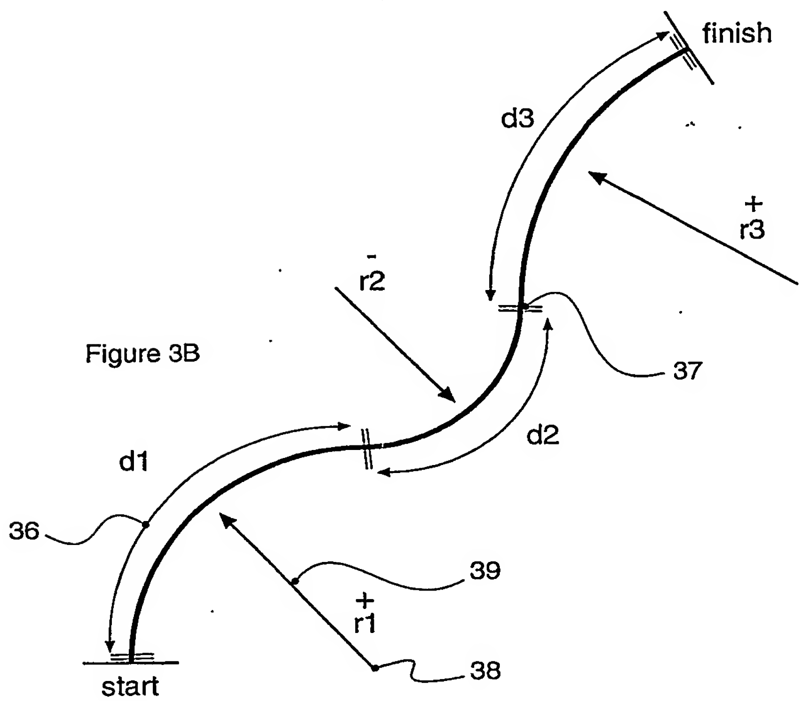

Figure 3B

Figure 3C

Radius Arc	Length	Distance	Steering Angle
+ r1	d1	d1	x
- r2	d2	d1+d2	y
+ r3	d3	d1+d2+d3	z